



surface 84 after passing around right edge 76 and left edge 78. Many prior art designs have these flow conditions along the entire length of their working surface areas.

On the opposite stroke of that shown in Fig 2, the same flow patterns exist except that they are inverted. In this situation, the water approaches from the other side of blade 72 so that lower surface 84 is the attacking surface and upper surface 80 is the low pressure surface.

Fig 3 shows the angled orientation of 72 taken at line 3-3 of Fig 1. Relative to the direction of oncoming flow 85, right edge 76 is seen to be the leading edge from this view while left edge 78 is the trailing edge. The cross sectional shape of this embodiment is shown to be symmetrically tapered at right edge 76 and left edge 78. This enables this embodiment to generate efficient levels of lift when the direction of flow reverses around blade 72 on reciprocating strokes. However, this embodiment can also employ an asymmetrical hydrofoil shape that works most effectively during one particular stroke. For example, a symmetrical or asymmetrical tear drop cross sectional shape can be used.

From the view shown in Fig 3, it can be seen that this segment of blade 72 is at a significantly reduced angle of attack relative to oncoming flow 85. The streamline next to lower surface 84 is flowing smoothly in an attached manner. This attached flow condition shows that separation is greatly reduced along the low pressure surface of blade 72. This significantly reduces drag and increases lift. It is preferred that blade 72 is twisted over a substantial portion of its length so that a significant portion of blade 72 is oriented at a significantly reduced angle of attack.

Because this reduced angle of attack increases attached flow along the low pressure surface, a strong low pressure field is formed along lower surface 84 as water curves around this surface. Efficiency is high because the flow of water around the lower surface 84 (the low pressure surface or lee surface) is not blocked or restricted. While this low pressure field forms, a high pressure field forms along upper surface 80 as water pushes against this surface. The pressure difference existing between these two pressure fields creates lift vector 86, which is

As the outer streamline a begins to curve around the outer edge of lower blade 168, it separates from the lower surface of lower blade 168. This is because lower blade 168 is oriented at an undesirable angle of attack relative to oncoming flow 164. The resultant separation stalls lower blade 168 and prevents a low pressure field from forming along the lower surface (low pressure surface on this stroke) of lower blade 168. This prevents lift from being created and creates high levels of drag from transitional flow. After streamline a separates from the lower surface of 168, it forms a large induced drag type vortex below the lower surface of 168. This further destroys lift and creates significantly large levels of induced drag.

As streamline b tries to curve around the outer end of upper blade 166, it is blocked by the upper surface (attacking surface) of lower blade 168. This causes streamline b to curl back around toward the lower surface (lee pressure surface) of upper blade 166 and form a rotating eddy in the space between upper blade 166 and lower blade 168. Because the dihedral orientation of lower blade 168 blocks water flowing around the outer end of blade 166, this water cannot merge in a constructive manner with the water exiting the attacking surface of blade 166 at its inner side edge (near vertical blade 174). In addition, the eddy formed between blade 166 and blade 168 causes the water to flow backward along the lower surface (lee surface) of upper blade 166. This flow is oriented in the opposite direction needed to generate lift. Consequently, The dihedral orientation of lower blade 168 prevents attached flow conditions from occurring along the lower surface of upper blade 166. Furthermore, the dihedral orientation of lower blade 168 creates highly undesirable turbulence patterns which stalls upper blade 166 and prevents it from generating lift.

Just as a stalled airplane wing can prevent an airplane from generating the needed lift to get off the ground, the severely stalled blades in this swim fin prevent them from generating adequate levels of lift. As a result, propulsion is poor and drag is exceedingly high. When considering that the presence of one or two stalled blades on other prior art swim fins create excessive levels of drag which often cause painful muscle cramps, the drag created by the four completely stalled blades in Barnoin's swim fin can be unbearable. The combination of this

swim fin's propensity to generate high levels of induced drag and transitional flow on all four blades, places drag generation at unusable levels.

The eddy created between upper blade 166 and lower blade 168 forms into a powerful induced drag vortex that further destroys lift and increases drag. This induced drag vortex creates an outward flow condition along the upper surface of upper blade 166 near the outer edge of upper blade 166. As a result, streamline c is deflected outward and drawn toward the vortex existing between upper blade 166 and lower blade 168. Although streamline d is able to flow inward along the upper surface of upper blade 166, the lower surface of upper blade 166 is completely stalled out. This prevents upper blade 166 from generating a substantial pressure difference between its opposing surfaces.

Description-Figs 9 to 13

Fig 9 shows a perspective view of an improved swim fin which has a recess along the swim fin's center axis. This recess extends from the trailing portion of the swim fin to a predetermined distance (in this case a significantly short distance) from the toe portion of a foot pocket 180. However, any desirable distance may be used. The recess divides the swim fin into a right blade half 182 and a left blade half 184. Right blade half 182 is made up of a flexible blade portion 186 and a right stiffening member 188. An outer edge 190 of flexible portion 186 is connected to an inner edge 192 of stiffening member 188 in any suitable manner. For instance, flexible portion 186 and stiffening member may be molded as one piece out of the same material. An outer edge 194 of stiffening member 188 is located opposite from inner edge 192. Stiffening member 188 tapers in thickness toward a trailing tip 195. Flexible portion 186 is seen to have a trailing edge 196, an inner edge 198, and an upper surface 199.

Left blade half 184 is constructed in the same manner as right blade half 182. Left blade half 184 has a flexible blade portion 200 and a left stiffening member 202. An outer edge 204 of flexible portion 200 is attached to an inner edge 206 of stiffening member 202 in any suitable manner. Opposite from inner edge 206 is an outer edge 208 of stiffening member 202. Flexible

Braunkohlen's and Barnoin's blade designs. For this reason, the same severe structural inadequacies shared by both designs are displayed in Figs 12 and 13 as one simplified embodiment. Fig 12 shows a top perspective view of such a prior art swim fin spreading apart in a spanwise manner during use. Fig 13 shows a side perspective view of the same swim fin shown in Fig 12 except that its blades are seen to bend backward around a substantially transverse axis during use. Just as Fig 11 shows the problems created when the prior art blades are made of a significantly rigid material, Figs 12 and 13 show the problems the same prior art design creates when the blades are made out a highly flexible material.

Operation-Figs 9 to 13

The embodiment shown in Figs 9 and 10 is designed to permit right blade half 182 and left blade half 184 to twist along a substantially lengthwise axis. This embodiment uses the same fundamental methods for generating lift that are described in Figs 5 to 7 except that in Figs 9 and 10, the blades are able to twist so that they can achieve an anhedral orientation during each reciprocating stroke.

The structure of this embodiment permits right blade half 182 and left blade half 184 to bend efficiently around a substantially lengthwise axis during use so that they can attain a twisted form. Right blade half 182 and left blade half 184 are preferably made of a material that can be relatively rigid when it is substantially thick, and relatively flexible when it is substantially thin. This allows stiffening members 188 and 202 to be substantially rigid while portions 186 and 200 are substantially flexible. For instance, a fiber reinforced thermoplastic having an appropriate variance in thickness may be used. Any suitable material or combinations of materials may be used as well in any suitable arrangement to produce such desired results. The rapid decrease in thickness near the outer side edges of each blade half enables flexible portion 186 and flexible portion 200 to deform significantly near these outer side edges. This is because such rapid tapering substantially reduces anti-bending stress forces along outer edge 190 of flexible portion 186, as well as along outer edge 204 of flexible portion 200. Since deformation can occur substantially close to the outer side edges of each blade half, separation is significantly reduced

use. It is also intended that any deformation exhibited during use along the lengths of stiffening members 188 and 202 does not occur in an amount or manner which may significantly inhibit flexible blade portions 186 and 200 from efficiently deforming in an anedral manner.

Preferably, the degree of rigidity should be selected to significantly reduce the tendency for blade half 182 and 184 to bend backward around a substantially transverse axis during use under the exertion of vertical component 232 of lift vector 226, and under the exertion of vertical component 228 of lift vector 224, respectively. It is also preferred that the degree of rigidity should be selected to significantly reduce the tendency for blade half 182 and 184 to spread apart from each other in a substantially sideways manner during use under the exertion of horizontal component 234 of lift vector 226 and horizontal component 230 of lift vector 224, respectively. This significantly reduces the degree of lost motion existing between strokes. It also enables each blade half to substantially maintain orientations that efficiently generate significantly high levels of lift. Furthermore, such rigidity enables the lift generated by blade half 182 and blade half 184 to be efficiently transferred onto foot pocket 180 which in turn pushes forward upon the swimmer's foot for propulsion.

In Fig 10, oncoming flow 222 is illustrated by a series of streamlines flowing around blade halves 182 and 184. The streamlines curving around stiffening members 188 and 202 toward lower surfaces 218 and 220, flow in a smooth and attached manner. This permits high levels of lift to be efficiently generated on blade halves 182 and 184. Also, the streamlines flowing along upper surfaces 199 and 214 flow in an inward direction toward the recess between the blades. This illustrates that outward directed spanwise cross flow conditions have been significantly reduced. Because the streamlines above and below blade halves 182 and 184 are able to merge in a constructive manner, lift is efficiently generated. This is because such a merging causes the water flowing a greater distance around the lee surface of each blade half to flow at a faster rate in order to keep up with the water flowing a shorter distance across the attacking surfaces of the blades. This increase in flow speed along the lee surfaces causes the water flowing across these surfaces to experience a decrease in pressure. It is this decrease in pressure which creates lift on the blades.

The presence of inward flowing streamlines above upper surfaces 199 and 214 demonstrate that fluid pressure is increasing above these surfaces. This combines with the low pressure field generated below lower surfaces 218 and 220 to further increase lift by increasing the overall difference in pressure existing between the attacking surfaces and the lee surfaces of the blades. Some of the streamlines are seen to pass through the recess existing between inner edges 198 and 212. Such movement through this recess permits flow exiting the attacking surfaces to merge with the flow exiting the lee surfaces, thereby making lift generation possible according to Bernoulli's principle. In addition, this passage of water through the recess also permits excess back pressure along the attacking surfaces to be vented through this recess. This prevents such back pressure from building up to levels which cause the flow along the attacking surfaces to back up and expand in an outward spanwise direction.

Because outward spanwise cross flow conditions are significantly reduced, or even eliminated along the attacking surfaces, the water flowing across these surfaces is efficiently jettisoned in a focused manner toward the trailing edges of the blades. This significantly increases forward propulsion when combined with lift generating attached flow conditions along the lee surfaces of the blades. The streamlines shown in Fig 10 which are flowing in an inward direction along upper surfaces 199 and 214, are also flowing at a significantly fast rate toward the trailing edges of the blades (out of the plane of the paper toward the viewer). The ratio of inward spanwise directed flow to aftward directed flow can be varied according to desire.

Wind tunnel tests of smoke trails flowing around blade designs using the flow control methods of the present invention demonstrate significantly reduced levels of outward spanwise cross flow conditions along the attacking surfaces of the blades. In addition, these tests demonstrate that substantially high levels of attached flow conditions occur along the lee surfaces of the blades. Comparative smoke trail tests of many prior art blade designs show that significantly high levels of outward spanwise flow conditions occur along their attacking surfaces. Such comparative tests of prior art designs also show that significantly high amounts of flow separation and induced drag vortex formation along their lee surfaces.

as the swim fin is kicked forward after being at rest. Such backward bending occurs because the structure of each blade is highly vulnerable to bending around a transverse axis when it is made flexible enough to experience significant anhedral deformation along its length.

Experiments with test models having the structural inadequacies shown in Figs 12 and 13 demonstrate that such dramatic levels of undesirable deformation occur commonly when highly resilient materials are used. Such experiments show that propulsion is poor for blades having these deformation problems. Experiments also show that merely increasing the rigidity of the material used for each blade, only causes a larger portion of each blade to remain at an excessively high angle of attack which causes stall conditions that destroy lift and generate high levels of drag. These problems render such prior art designs unusable.

Looking back to the embodiment of the present invention shown in Figs 9 and 10, it can be seen that the combination of significantly rigid stiffening members 188 and 202 with highly resilient flexible blade portions 186 and 200, respectively, efficiently solve the performance debilitating structural problems inherent to the prior art. Unlike the prior art, the methods of the present invention provide the blades with sufficient flexibility to twist in an anhedral manner around a significantly lengthwise axis while providing sufficient rigidity to permit the blades to substantially maintain their orientations during use. This permits drag producing stall conditions to be replaced by lift generating attached flow conditions on each blade. In addition, the blades have enough structural integrity to efficiently transfer their newly derived lift to foot pocket 180 so that the swimmer is propelled forward. By significantly reducing the occurrence of spanwise spreading and backward bending during use, the methods of the present invention permit lost motion to be significantly reduced as well.

Not only did Barnoin and Braunkohlen not offer methods for establishing lift generating attached flow conditions along the lee surfaces of their blade designs, they did not mention that they were aware that this is necessary, nor did they mention that they were aware that their blades create high levels of drag from high levels of stall conditions and induced drag vortex formation. Not only did Barnoin and Braunkohlen not offer any methods for preventing their

blades from spreading apart in a spanwise direction, neither of them mentioned that they were aware that such a problem existed with their designs. They also did not mention that they were aware that the use of highly resilient and deformable materials renders their blades highly vulnerable to excessive levels of lost motion due to backward bending around a transverse axis.

Description-Figs 14 to 23

Fig 14 shows a cut-away perspective view displaying the right half of the same swim fin shown in Fig 9. Because both blade halves of this embodiment function in the same manner, Fig 14 solely describes the right half. Also, the cut-away view in Fig 14 allows one to see the significantly thick portion of flexible portion 186 that extends below foot pocket 180 to form the sole of foot pocket 180 (discussed previously in Fig 9). Another reason why only the right blade half is shown is because this design may also be used with only one blade half and no other companion blades or blade halves. Such an embodiment is similar to that shown in Figs 1-4, except that a flexible blade is provided in the figures below to permit the angle of attack to be changed on each reciprocating stroke. Alternate embodiments may employ any desirable number of additional blades in any desirable arrangement or configuration. However, the preferred embodiment will employ two substantially symmetrical blade halves.

In Fig 14, a broken line shows the presence of a bending zone 238 along flexible portion 186 which extends from the base of the center recess near foot pocket 180 to trailing edge 196 near trailing tip 195.

Fig 15 shows a cross sectional view taken along the line 15-15 from Fig 14. In Fig 15, bending zone 238 is displayed by a vertically oriented broken line extending above and below the plane of 186. Bending zone 238 is shown in this manner so that its position on flexible portion 186 may be seen from this cross sectional view. An oncoming flow 240 is displayed by a series of streamlines flowing toward and around right blade half 182. A neutral position 242 of flexible portion 186 is displayed by horizontally aligned broken lines. A semi-flexed position 244 of flexible portion 186 is displayed by downward angled solid lines. A highly flexed

position 246 of flexible portion 186 is displayed by downward angled broken lines. The deformation of blade half 182 to flexed positions 242 and 246 occur as the swim fin is kicked upward through the water with upper surface 199 being the attacking surface. It can be seen that the deformation of flexible portion 186 from neutral position 242 to either semi-flexed position 244 or highly flexed position 246 occurs between bending zone 238 and inner edge 198. The portion of flexible portion 186 existing between bending zone 238 and stiffening member 188 remains substantially stationary relative to the orientation of stiffening member 188 under the exertion of oncoming flow 240. As the streamlines of oncoming flow 240 pass around the outside of stiffening member 188 when flexible portion 186 is deformed to position 244, a zone of separation 248 is formed along the low pressure surface of right blade half 182.

Fig 16 shows a cross sectional view taken along the line 16-16 from Fig 14. This sectional view taken at line 16-16 from Fig 14 occurs closer to trailing edge 196 than the sectional view taken along the line 15-15 from Fig 14, and also occurs closer to foot pocket 180 than the sectional view taken along the line 10-10 from Fig 9. In Fig 16, an oncoming flow 249 is displayed by two streamlines flowing toward and around right blade half 182 as the swim fin is kicked through the water during the same upward stroke as that occurring in Fig 15. Thus, oncoming flow 249 in Fig 16 is produced by the same kicking motion used to form oncoming flow 240 shown in Fig 15. In Fig 16, positions 242, 244, and 246 of flexible portion 186 are the same as those shown in Fig 15, except that in Fig 16 these positions are taken along the line 16-16 from Fig 14. In Fig 16, position 242 of flexible portion 186 is displayed by horizontally broken lines. Position 244 of flexible portion 186 is displayed by downward angled solid lines. Position 246 of flexible portion 186 is displayed by downward angled broken lines. Again, bending zone 238 is displayed by a vertically aligned broken line so that the position of bending zone 238 on flexible portion 186 can be seen from this view. Because bending zone 238 is substantially close to stiffening member 188, an increased portion of flexible portion 186 is able to deform to either position 244 or position 246 during use.

As the streamlines of 249 flow around the outside of stiffening member 188, a separation zone 250 is formed along the low pressure surface of right blade half 182. Separation 250 is

However, the reduced angle of attack achieved during use can occur at any desirable angle which is capable of offering improvements in performance.

Position 246 is shown in this example to illustrate that the structural characteristics of the swim fin prevent portion 186 from flexing between bending zone 238 and stiffening member 188 even if portion 186 is made of a highly resilient material. It is important to visualize how the position of bending zone 238 influences the deforming characteristics of portion 186. This permits the further improvements described ahead in the specification to be more fully understood and appreciated.

Fig 16 shows a cross sectional view taken along the line 16-16 from Fig 14. In Fig 16, the same positions 242, 244, and 246 shown in Fig 15 are viewed from another region of portion 186. When comparing Fig 16 to Fig 15, it can be seen that in Fig 16 bending zone 238 is significantly closer to stiffening member 188 than it is in Fig 15. Consequently, separation 250 shown in Fig 16 is substantially smaller than separation 248 shown in Fig 15. This is because in Fig 16, the region of portion 186 existing between bending zone 238 and stiffening member 188 is significantly smaller than it is in Fig 15. As a result, the streamline of oncoming flow 249 that is flowing around the outside of stiffening member 188 in Fig 16 is able to become re-attached to the low pressure surface (or lee surface) of portion 186. The rotational direction of separation 250 also assists in creating attached flow conditions along the low pressure surface of portion 186. This enables this region of right blade half 182 to generate lift vector 251 during use. Consequently, the trailing portions of right blade half 182 are highly efficient at generating lift. This efficiency increases with proximity to tip 195.

Alternate embodiments can create limited flow separation such as shown by separation 250 in Fig 16 as a method for creating re-attached flow conditions along portions of a blade that are at significantly high angles of attack. This is similar to the intentional formation of leading edge vortices by leading edge vortex flaps on delta wing fighter jets. Vortex generators in the form of ridges can be used to form leading edge vortices in a manner that enables flow to become re-attached further downstream on the foil's low pressure surface. As long as substantially

significantly high levels of twisting to occur under conditions of relatively light pressure with more structurally rugged materials.

As blade halves 182 and 184 twist to reduced angles of attack, the rigidity of stiffening members 188 and 202 reduces the tendency for each blade half to bend backward around a transverse axis or spread apart from each other during use. Consequently, each blade half is able to efficiently twist around a substantially lengthwise axis during use without deforming excessively around a substantially transverse axis and without experiencing excessive levels of spanwise spreading.

In the embodiment shown in Fig 19, stiffening members 188 and 202 are seen to increase in flexibility near tips 195 and 216, respectively. This is seen as stiffening members 188 and 202 arch backward in a controlled manner under water pressure exerted during use. This allows the direction of lift on panel 272 and panel 284 to become more aligned with the swimmer's direction of travel. Such increased flexibility also produces a whip-like snapping motion to occur near the tips of each blade half as the kicking direction is reversed between strokes. It is preferred that such an increase in flexibility is sufficiently limited to prevent the tip regions of each blade half from experiencing excessive levels of lost motion or sideways spreading. It is also preferred that stiffening members 188 and 202 remain sufficiently rigid enough across their entire length to create a significantly strong twisting moment during use within portions 186 and 200, respectively. It is also intended that stiffening members 188 and 202 are sufficiently rigid enough to permit blade halves 182 and 184 to substantially maintain orientations that are effective in generating significantly high levels of lift as such a lifting force is transferred from stiffening members 188 and 202 to foot pocket 180 during use.

Each blade half's resistance to twisting can be changed by either increasing or decreasing the transverse dimensions of each transverse recess. On right blade half 182 for instance, if the transverse dimensions of each recess is decreased, portion 186 becomes less able to attain a twisted shape during use. This is because the area of portion 186 existing between the outside end of each transverse recess and stiffening member 188 is unable to expand in a sufficient